

# The BES-III experiment at the high luminosity Tau-Charm factory

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Interesting results from BES-II and other experiments raised actually many new questions which shall be answered by its upgrade program, BEPCII and BES-III. The design and current status of BEPCII and BES-III are reported.

## I. PHYSICS MOTIVATION

In early 80's, Chinese government decided to build an  $e^+e^-$  collider running at the tau-charm energy region, called BEPC, which is completed in 1989. The only detector at the machine is called Beijing spectrometer(BES). In mid 90's, there has been a minor upgrade of the detector, which is then called BES-II. Since then, hundreds of papers have been published on the international journals, some with significant impacts to the community. The upgrade of BEPC was decided at the beginning of this century, called BEPCII, which has a designed luminosity of  $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ , an increase of a factor of 100. The corresponding detector, called BES-III, adopted latest detector technology to minimize systematic errors in order to match the unprecedented statistics.

The physics program of the BES-III experiment includes light hadron spectroscopy, charmonium, electroweak physics from charmed mesons, QCD and hadron physics, tau physics and search for new physics. Due to its huge luminosity and small energy spread, the expected event rate per year is historical, as listed in table I.

TABLE I:  $\tau$ -Charm productions at BEPCII in one year's running( $10^7\text{s}$ ).

Data Sample	CoM energy (MeV)	Luminosity ( $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ )	#Events per year
$J/\psi$	3097	0.6	$10 \times 10^9$
$\tau^+\tau^-$	3670	1.0	$12 \times 10^6$
$\psi(2S)$	3686	1.0	$3.0 \times 10^9$
$D^0\bar{D}^0$	3770	1.0	$18 \times 10^6$
$D^+D^-$	3770	1.0	$14 \times 10^6$
$D_s^+D_s^-$	4030	0.6	$1.0 \times 10^6$
$D_s^+D_s^-$	4170	0.6	$2.0 \times 10^6$

It is well known that  $J/\psi$  and  $\psi'$  decays is an ideal laboratory for light hadron studies since it has a huge production cross section with a very clean and gluon rich environment. We plan to study the meson and baryon spectroscopy, search for glueballs and other exotics such as hybrids and multi-quark states. Recently, BES-II found several new structures and threshold enhancements in various decays channels [1], which leads to a number of speculations. It is clear that more data is needed to understand these results,

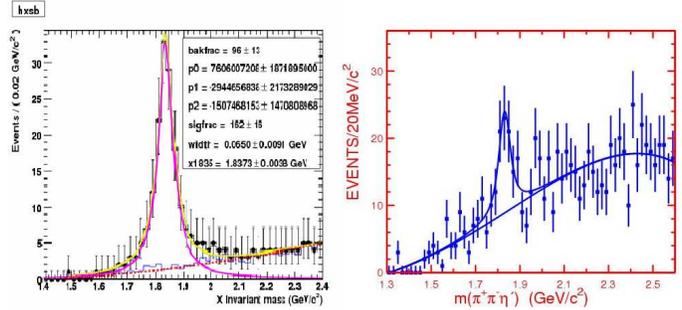


FIG. 1: A comparison of the X(1835) signal at BES-II and the corresponding expectation at BES-III. (a) 2.5 days of BES-III, (b) two years of BES-II

study their decay properties and establish a theoretical framework to accommodate them. Fig. 1 shows a comparison of the X(1835) signal at BES-II and the corresponding expectation at BES-III. The improvement comes mainly from the increase of luminosity by a factor of 100, and the decrease of the energy resolution of the electromagnetic calorimeter by a factor of 10. Similar results are expected for other new structures and threshold enhancements.

Recently, a lot of new XYZ resonance have been found above or below the open charm threshold from B decays. BES-III should be able to study the direct production of  $1^-$  states and some of the low mass states, such as  $Y(2175)$ . We will systematically study charmonium transitions and their decays, search for rare decays and new phenomena, and calibrate lattice QCD calculations.

For Charm physics, the precision of CKM matrix elements can be significantly improved by measuring the leptonic and semi-leptonic decays of charmed mesons, and test the unitarity of CKM matrix. The  $D\bar{D}$ -mixing can be measured at the level of  $10^{-4}$  and the CP violation will be searched for at the level of  $10^{-3}$ . Rare and forbidden decays can be searched for at a typical level of  $10^{-8}$ .

The tau mass measurement can be improved by a factor of two over the BES-II results with a new beam

energy calibration based on the Compton scatter technique.

A summary of BES-III physics program, called low book, is under preparation. It will be published at the beginning of next year.

## II. STATUS OF THE COLLIDER

The new BEPCII has two storage rings with a circumference of 224 m, one for electron and one positron, each with 93 bunches spaced by 8 ns [4]. The total current of the beam is designed to be 0.93 A, the crossing angle of two beams 22 mrad. The peak luminosity is expected to be  $10^{33} \text{cm}^{-2} \text{s}^{-1}$  at the beam energy of 1.89 GeV, the bunch length is estimated to be 1.5 cm and the energy spread  $5.16 \times 10^{-4}$ .

At this moment, all the LINAC equipments have been installed and successfully tested. Parameters such as the beam current, emittance and energy spread etc. for both electron and positron beams, have been measured. All the design specifications have been satisfied.

The storage rings have been installed in two phases. In the first phase, conventional magnets at the interaction region were installed and tested. Both electron and positron beams have been stored up to 500 mA with a reasonable life time. Synchrotron radiation beams have been delivered to user for about three months in total. Tests of  $e^+e^-$  collision have been performed with an estimated peak luminosity of about  $10^{31} \text{cm}^{-2} \text{s}^{-1}$ . In the second phase, superconducting quadrupoles for the final beam focusing at the interaction region have been installed and beams have successfully stored. Collision of  $e^+e^-$  beams have been observed and synchrotron radiation run will start soon.

We plan to move the BES-III detector into the interaction region early next year after the luminosity is more than  $3 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$  and the beam background is under control.

## III. STATUS OF THE BES-III CONSTRUCTION

The BES-III detector [2, 3], as shown in Fig. 2, consists of a drift chamber in a small cell structure filled with a helium-based gas, an electromagnetic calorimeter made of CsI(Tl) crystals, Time-of-Flight (TOF) counters for particle identification made of plastic scintillators, a muon system made of Resistive Plate Chambers (RPC), and a superconducting magnet providing a field of 1T. Current status of the construction is summarized in the following.

The drift chamber has a cylindrical shape with two chambers jointed at the end flange: an inner chamber

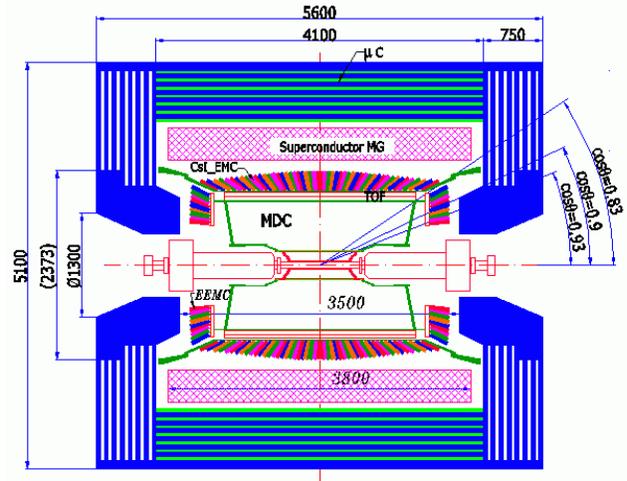


FIG. 2: Schematics of the BES-III detector.

without outer wall and an outer chamber without inner wall. There are a total of 6 stepped end flanges made of 18 mm Al plates in order to give space for the focusing magnets. The inner radius of the chamber is 63 mm and the outer radius is 810 mm, with a length of 2400 mm. Both the inner and outer cylinder of the chamber are made of carbon fiber with a thickness of 1 mm and 10 mm respectively. A total of 6300 gold-plated tungsten wires (3% Rhenium) with a diameter of 25  $\mu\text{m}$  are arranged in 43 layers, together with a total of 22000 gold-plated Al wires for field shaping. The small drift cell structure of the inner chamber has a dimension of  $6 \times 6 \text{mm}^2$  and the outer chamber of  $8 \times 8 \text{mm}^2$ , filled with a gas mixture of 60% helium and 40% propane. The designed single wire spatial resolution and  $dE/dx$  resolution are 130  $\mu\text{m}$  and 6%, respectively.

All the wiring have been completed with a very high quality, the wire tension and the leakage current are well under control. The assembly of the chamber has been completed together with all preamplifiers and related electronics. The whole chamber has been tested using cosmic-rays for three months. The obtained single wire resolution is about 120  $\mu\text{m}$ , as shown in Fig. 3, well satisfying our design goal. The chamber has now been installed successfully into the BES-III detector.

The CsI(Tl) crystal electromagnetic calorimeter consists of 6240 crystals, 5280 in the barrel, and 960 in two endcaps. Each crystal is 28 cm long, with a front face of about  $5.2 \times 5.2 \text{cm}^2$ , and a rear face of about  $6.4 \times 6.4 \text{cm}^2$ . All crystals are tiled by  $1.5^\circ$  in the azimuth angle and  $1-3^\circ$  in the polar angle, respectively, and point to a position off from the interaction

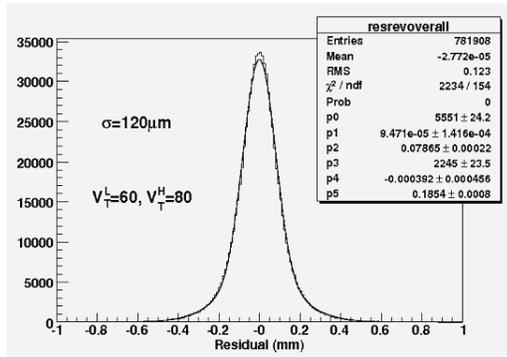


FIG. 3: Single wire resolution of the MDC from a cosmic-ray test

point by a few centimeters. The designed energy and position resolution are 2.5% and 6 mm at 1 GeV, respectively.

All the crystals have been produced and shipped, been tested, and assembled. Fig. 4 shows the test results of the light yield, uniformity and radiation hardness. All the barrel crystals have been installed into the mechanical structure, which has been installed into the BES-III detector as well.

The readout electronics of crystals, including preamplifiers, main amplifiers and charge measurement modules are tested at the IHEP E3 beam line together with a crystal array and photodiodes. Results from the beam test shows that the energy resolution of the crystal array reached the design goal of 2.5% at 1 GeV and the total noise achieved the level of less than 1000 equivalent electrons, corresponding to an energy of 220 KeV.

The particle identification at BES-III is based on the momentum and  $dE/dx$  measurements by the drift chamber, and the TOF measurement by plastic scintillators. The barrel scintillator bar is 2.4 m long, 5 cm thick and 6 cm wide. A total of 176 such scintillator bars constitute two cylinders, to have a good efficiency and time resolution. For the endcap, a total of 48 fan-shaped scintillators form a single layer. A 2-inch fine-mesh phototube is directly attached to each end of the scintillator to collect the light. The intrinsic time resolution is designed to be 90 ps including contributions from electronics and the common start/stop time. Such a time resolution, together with contributions from the beam size, momentum uncertainty, etc. can distinguish charged  $\pi$  from K mesons for a momentum up to 0.9 GeV at the  $2\sigma$  level.

Beam tests show that the intrinsic time resolution can be better than 90 ps and 75 ps for the barrel and the endcap TOF counters, respectively. Currently, all the PMTs and scintillators have been delivered and tested. The average attenuation length of all barrel scintillators is 4.8 m and the relative light yield exceeds our specification. All barrel scintillator have

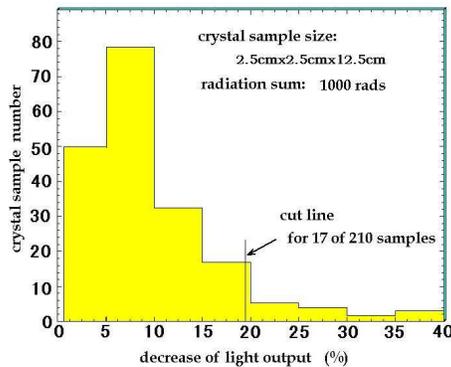
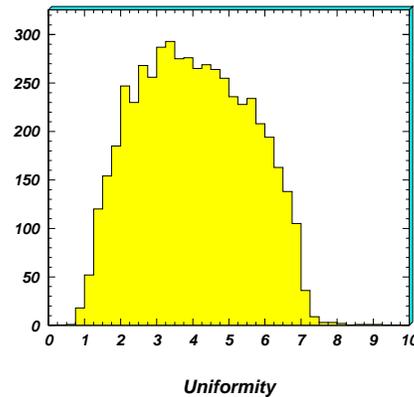
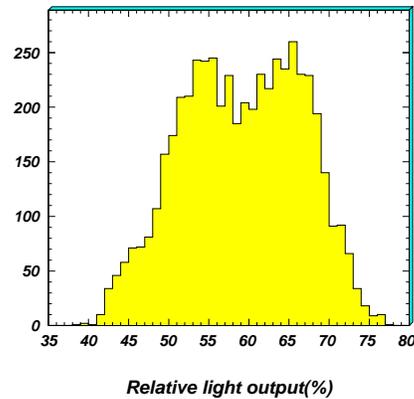


FIG. 4: Test results of all CsI(Tl) crystals. Top: relative light yield with respect to the reference crystal; middle: Uniformity along the long axis of the crystal; bottom: radiation hardness

been assembled outside of the MDC and installed into the BES-III detector successfully.

The BES-III muon chamber is made of Resistive Plate Chambers(RPC) interleaved in the magnet yoke. There are a total of 9 layers in the barrel and 8 layers in the endcap, with a total area of about 2000  $\text{m}^2$ . The readout strip is 4 cm wide, alternated between layers in x and y directions. The RPC is made of bakelite with a special surface treatment without

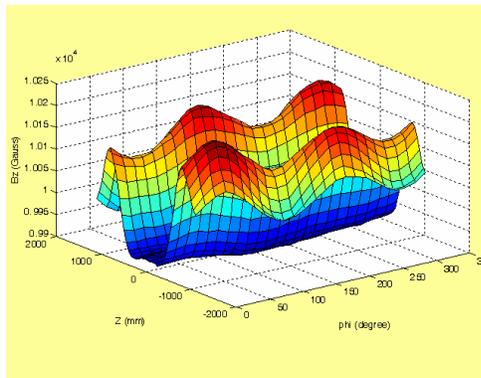


FIG. 5: Field map inside the super-conducting magnet

linseed oil [5]. Such a simple technique for the RPC production shows a good quality and stability at a low cost. All RPCs have been manufactured, tested, assembled and installed with satisfaction.

The BES-III super-conducting magnet has a radius of 1.48 m and a length of 3.52 m. It use the Al stabilized NbTi/Cu conductor with a total of 920 turns, making a 1.0T magnetic field at a current of 3400 amp. The total cold mass is 3.6 t with a material thickness of about  $1.92 X_0$ . In collaboration with WANG NMR

of California, the magnet is designed and manufactured at IHEP.

The magnet was successfully installed into the iron yoke of the BES-III, together with the valve box. A stable magnetic field of 1.0T at a current of 3368 A was achieved. The field mapping together with super-conducting quadrupole magnets for final focusing of the beam has been completed, and results are shown in Fig. 5. The uniformity of the magnetic field is satisfactory.

The BES-III offline software consists of a framework based on GAUDI, a Monte Carlo simulation based on GEANT4, an event reconstruction package, a calibration package and a database package using MySQL. Currently all codes are working as a complete system, and tests using cosmic-ray data and beam test data are underway. Analysis tools such as the particle identification, secondary vertex finding, kinematic fitting, event generator and partial wave analysis are still under development. Data challenge of the whole system is planed.

In summary, the BEPCII and BES-III construction went on smoothly. Currently all the mass production of detector components have completed, most of the assembly and installation of the detector are finished. We plan to take data in 2008.

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- [1] see for example, M. Ablikim *et al.*, Phys. Rev. Lett. **91** (2003)022001; Phys. Rev. Lett. **93**(2004)112002; Phys. Rev. Lett. **95**(2005)262001; Phys. Rev. Lett. **96**(2006)162002; Phys. Rev. Lett. **97**(2006)142002.  
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